**Annex 3.**

***Form of opening (renewal) for Project /***

***Sub-project of LRIP***

 **APPROVED**

 **JINR DIRECTOR**

 **/**

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**PROJECT PROPOSAL FORM**

Opening/renewal of a research project/subproject of the large research infrastructure project within the Topical plan of JINR

**1. General information on the research project of the theme/subproject of the large research infrastructure project (hereinafter LRIP subproject)**

* 1. **Theme code / LRIP** (for extended projects) - *the theme code includes the opening date, the closing date is not given, as it is determined by the completion dates of the projects in the topic.*

**1.2 Project/LRIP subproject code** (for extended projects)

**1.3 Laboratory** Bogoliubov Laboratory of Theoretical Physics

**1.4 Scientific field** Theoretical Physics

**1.5 Title of the project/LRIP subproject** QCD and hadron structure

**1.6 Project/LRIP subproject leader(s)** I.V.Anikin, S.V. Mikhailov, O.V. Teryaev

**1.7 Project/LRIP subproject deputy leader(s) (scientific supervisor(s))**

**2 Scientific case and project organization**

**2.1 Annotation**

Lacking a complete theoretical understanding of the color confinement, the only method of applying QCD, is based on the factorization of the short-distance (perturbative) and long-distance (nonperturbative) dynamics. The conventional systematic way of dealing with

the long-distance part is to parametrize it in terms of matrix elements of quark and gluon

operators between hadronic states generating GPDs, DAs, TMDs etc.

These matrix elements have to be either extracted from experiment or be determined

on the lattice. In many phenomenological applications they are usually modeled in terms of

various nonperturbative methods or models.

The main objective of the project is to develop a comprehensive theoretical

frameworks to study the multi-dimensional partonic content of the hadrons by combining

various approaches based on the factorization theorem and starting from the first principles of QCD.

**2.2 Scientific case** (aim, relevance and scientific novelty, methods and approaches, techniques, expected results, risks)

For many years, theoretical and experimental studies of the nucleon structure have been restricted to a

one-dimensional picture along a light-cone direction. Within this one dimensional picture, quark and gluon contents of the nucleus are described by the parton distribution functions (PDFs) which depends on the longitiduinal momentum of the parton inside the hadron.

The last decade have witnessed a tremendous effort to go beyond this one dimensional description of the nucleon. Recent improvements in experimental facilities, such as increased electron beam luminosities and polarization degrees, detector resolution and coverage, and advanced theoretical computation frameworks, such as calculating radiative and power corrections to complementary sets of observables, provide a break through to investigate the multi-dimensional partonic content of the nucleon which is also referred to as hadron tomography.

In this respect, the multi-dimensional parton distribution functions such as transverse-momentum-dependent distribution functions (TMDs) or generalized parton distribution functions (GPDs) have been the key subjects of both experimental and theoretical studies.

With the advent of new generation colliders such as Electron Ion Collider (EIC) in the USA, Large Hadron electron Collider (LHeC) at CERN, the theoretical improvements of these distribution functions are mandatory for a precise comparison with the data. Motivated from this need, the main objective of the proposed project is to develop a comprehensive theoretical framework to study the multi-dimensional partonic content of the hadrons by combining various approaches starting from the first principles of QCD. This objective will be achieved by studying the following tasks:

1. Analytic evaluation of 3-loop 2-point Feynman master-integrals with composite external vertices for arbitrary indices of propagators. These master integrals could be instrumental in calculating $β\_{0}^{n−1}$ contributions in correlators of two composite quark currents in QCD and subleading (in the number *N* of matter fields) terms in large-*N* expansions of beta-functions in gauge theories. ($β\_{0}^{}$ stands for the one-loop coefficient of the QCD beta-function expansion).

2. Calculation of $a\_{s}^{2}\left(a\_{s}β\_{0}\right)^{n−1}$ and $a\_{s}^{3}β\_{1}\left(a\_{s}β\_{0}\right)^{n−2}$ contributions in the nonsinglet ERBL evolution kernel and correlator of two vector composite quark currents in QCD. In the special case $n=2$, these terms and $a\_{s}\left(a\_{s}β\_{0}\right)^{n}$-term calculated previously provide all perturbative corrections related to the strong coupling running in N3LO QCD sum rules for the twist-2 pion distribution amplitude. This should allow us to clarify numeric hierarchy among different parts of the beta-expansion for the correlator and kernel in the orders $a\_{s}^{2}$ и $a\_{s}^{3}$ ($a\_{s}$ and $β\_{n}^{}$ are the strong coupling and $\left(n+1\right)$-loop coefficient of the beta-function expansion in QCD, resp.)

3. The analytical and numerical optimizations of perturbation series are expected to be performed.

For observables using beta-expansion and renormalization group in QCD. It is planned to improve estimates of : R[e-e+ ->hadrons], width of tau-decay, Bjorken polarized SR that are known in multiloop calculation and compare our results with experimental data.

4. Calculation of pion electromagnetic form factors in framework of light-cone sum rules in the low and (or) moderate energy regime. The domain of framework applicability will be expand by usage analytic perturbation theory in order 0(\alpha\_s) . The planned predictions will be compared with precision Jlab experiment and similar results to pion transition FF.

5. The revision of distribution amplitudes (leading twist) of (pseudo)scalar and (longitudinal and transverse) vector mesons within QCD sum rules taking into account new QCD corrections 0(\alpha^2\_s) obtained by us for all of its components.

6. The derivation and analysis of full differential equation system for Feynman integral with multiple parameters of masses and impulses. Full differential system and its specialization with special values of parameters could help to research the properties of Feynman integrals. With the help of Mellin-Barnes integral representation differential relations for Feynman integral with arbitrary powers of propagator, masses and external impulses are planned tob e obtained. The special attention will be paied for the special cases of relations between the exponents of propagators and dimension of space-time, at which some of Feynman integrals degenerate to the Puiseux series.

7. Research of tau lepton decays and processes of electron-positron annihilation into mesons including the processes with three pseudoscalar mesons in the final state. It is necessary for theoretical description of the known experimental data and for verification of the used model for the new classes of processes.

8. Continuation of research of the inner structure and nature of the meson interaction at low energies by using the Nambu–Jona-Lasinio model. It can improve the understanding of the mechanisms of meson interactions in the nonperturbative QCD region.

9. The study of hadronic structure function of Drell-Yan processes in framework of perturbative QCD in $α\_{s}^{2}$ order of coupling constant. It will be check of Lam-Tung identity in $α\_{s}^{2}$ order of strong coupling constant.

10. The study of dark axion portal, implementation to fixed target experiments to obtain bounds for model. Bounds is needed for analysis of New physics and for NA64 experiment, in particular. Visible mode of axion or dark photon will be studied.

11. Study of the sum rules for hadron fragmentation functions (FFs) in quantum chromodynamics (QCD) with use of the generalized truncated Mellin moments approach (TMM).

12. Analytical and numerical optimization of perturbative series for observables using the renormalization group in QCD.

13. Study of anomalous transport phenomena in a relativistic quantum medium associated with the curvature of space-time. The study of anomalous transport phenomena is related to the fundamental question of the relationship between gravity, quantum physics and thermodynamics. The search for similar transport phenomena is carried out in experiments with collisions of isobars of heavy nuclei and at the level of quasiparticles in a condensed state.

14. On the base of analysis of experimental data on the elastic differential cross sections in the energy range 7 -13 TeV, including new data at very small momentum transfer, obtained by ATLAS Collaboration at 13 TeV, examine the methods of extraction the size of the total cross sections, to understand a tension between the different sizes, obtained by different Collaborations. Explore Influence of hadron potential at large distances on the sizes, which determined the peculiarity of the scattering amplitude, on sizes of the extracted total cross sections. Investigate the energy dependence and crossing properties of the new anomalous terms of the elastic amplitude of proton-proton and proton-antiproton scattering. Determine the structure of the elastic scattering amplitude in the framework of the High Energy Genarelized Structure model with taking into account the electromagnetic and gravitomagnetic hadron structure at NICA energies to obtain the possibility determined the structure of the spin-depended scattering amplitudes at NICA energies.

15. The new-found types of transverse momentum dependent parton distributions have been planned to study within the original frame. The new approach involves the new-found additional contribution in the inverse Radon transforms.

16. Study the phase diagram of SU(2)-Higgs Electroweak theory. Study of Z(N) symmetry and thermodynamic properties of meta-stable states at very high temperature in the context of QCD and Electroweak theory.

17. It is planned to establish a computational framework to analyze CMS Open Data and perform physics measurements.

**2.3 Estimated completion date**

**2.4 Participating JINR laboratories**

**2.4.1** **MICC resource requirements**

|  |  |
| --- | --- |
| **Computing resources** | **Distribution by year** |
| 1st year | 2nd year  | 3rd year | 4th year  | 5th year  |
| Data storage (TB)- EOS- Tapes |  |  |  |  |  |
| Tier 1 (CPU core hours) |  |  |  |  |  |
| Tier 2 (CPU core hours) |  |  |  |  |  |
| SC Govorun (CPU core hours)- CPU- GPU |  |  |  |  |  |
| Clouds (CPU cores) |  |  |  |  |  |

**2.5. Participating countries, scientific and educational organizations**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  **Organization** | **Country** | **City** | **Participants** | **Type** **of agreement** |
| University of Iquique, Santiago  | Chile | Santiago  | Dr. Cesar Ayala |  |
| Skobeltsyn Institute of Nuclear Physics, Moscow State University | Russia | Moscow | Maria Platonova |  |
| Institute of Modern Physics, Chinese Academy of Sciences | China | Lanzhou  | Xurong Chen, Ya-Ping Xie |  |
| Department of Physics, University of Tehran | Iran | Tehran | Muhammad Goharipour |  |
| School of Particles and Accelerators, Institute for Research inFundamental Sciences (IPM),  | Iran | Tehran |  K. Azizi |  |
| National Centre for Nuclear Research (NCBJ), | Poland | Warsaw | Lech Szymanowski  |  |
| ISDCT SB RAS | Russia | Irkutsk | Andrey Radzhabov |  |
| INR RAS | Russia | Moscow | Dmitry Kirpichnikov |  |
| University of Tübingen | Germany | Tübingen | Valery LyubovitskijWerner Vogalsang |  |
| University. Andres Bello | Chile | Santiago | Sergey Kuleshov, Sergey Kovalenko  |  |
| Hamburg  University | Germany | Hamburg | Bernd Kniehl, Oleg Veretin, Sven Moch |  |
| Sun Yat-Sen University | Chine | Sun Yat-Sen | Pengming Zhang Liping Zou |  |
| Landau Institute of Theoretical Physics | Russia | Chernogolovka | Nikolai Nikolaev |  |
|  |  |  |  |  |
|  |  |  |  |  |

**2.6. Key partners** *(those collaborators whose financial, infrastructural participation is substantial for the implementation of the research program. An example is JINR's participation in the LHC experiments at CERN).*

**3. Manpower**

**3.1. Manpower needs in the first year of implementation**

|  |  |  |  |
| --- | --- | --- | --- |
| **№№****n/a** | **Category of personnel** | **JINR staff,** **amount of FTE** | **JINR Associated** **Personnel,****amount of FTE** |
| 1. | research scientists | 20 | 5 |
| 2. | engineers |  |  |
| 3. | specialists |  |  |
| 4. | office workers |  |  |
| 5. | technicians |  |  |
|  | **Total:** |  |  |

**3.2. Available manpower**

**3.2.1. JINR staff**

|  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **No.** | **Category of personnel** | **Full name** | **Division** | **Position**  | **Amount** **of FTE** |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
| 1. | research scientists | Anikin Igor | BLTP | Head of a sector |  1 |  |  |  |  |  |
|  |  | GoloskokovSergej | BLTP | Leading researcher |  1 |  | GoloskokovSergej |  |  |  |
|  |  | Mikhailov Sergej | BLTP | Leading researcher | 1 |  |  |  |  |  |
|  |  | Selyugin Oleg | BLTP | Leading researcher | 1 |  |  |  |  |  |
|  |  | Silenko Alexandr | BLTP | Leading researcher | 1 |  |  |  |  |  |
|  |  | Strozik-Kotlorz Dorota | BLTP | Leading researcher | 1 |  |  |  |  |  |
|  |  | Bytiev Vladimmir | BLTP | Senior researcher | 1 |  |  |  |  |  |
|  |  |  VolchanskiyNikolai | BLTP | Senior researcher | 1 |  |  |  |  |  |
|  |  | ZhevlakovAlexej | BLTP | Senior researcher | 1 |  |  |  |  |  |
|  |  | Pivovarov Alexej | BLTP | Senior researcher | 1 |  |  |  |  |  |
|  |  | Nguen Hoang Wu | BLTP | Senior researcher | 1 |  |  |  |  |  |
|  |  | Pimikov Alexandr | BLTP | Senior researcher | 1 |  |  |  |  |  |
|  |  | Prokhorov Georgy | BLTP |  Researcher | 1 |  |  |  |  |  |
|  |  | Sazonov Andrej | BLTP | Researcher | 1 |  |  |  |  |  |
|  |  | Shohonov Denis | BLTP | Junior researcher | 1 |  |  |  |  |  |
|  |  | Khakimov Roman | BLTP | Senior laboratory assistant | 1 |  |  |  |  |  |
|  |  | Zakharov Valentin | BLTP | Principle Researcher | 0.5 |  |  |  |  |  |
|  |  | Krasnikov Nikolai | BLTP | Principle Researcher | 0.5 |  |  |  |  |  |
|  |  | Saleev Vladimir | BLTP | Leading researcher | 0.5 |  |  |  |  |  |
|  |  | Oganesian Armen | BLTP | Senior researcher | 0.5 |  |  |  |  |  |
| 2. | engineers |  |  |  |  |  |  |  |  |  |
|  |  |  |  |  |  |  |  |  |  |  |
| 3. | specialists |  |  |  |  |  |  |  |  |  |
| 4. | technicians |  |  |  |  |  |  |  |  |  |
|  | **Total:**  |  |  |  |  |  |  |  |  |  |

**3.2.2. JINR associated personnel**

|  |  |  |  |
| --- | --- | --- | --- |
| **No.** | **Category of personnel**  | **Partner organization** | **Amount of FTE** |
| 1. | research scientists |  |  |
| 2. | engineers |  |  |
| 3. | specialists |  |  |
| 4. | technicians |  |  |
|  | **Total:**  |  |  |

**4. Financing**

**4.1 Total estimated cost of the project/LRIP subproject**

The total cost estimate of the project (for the whole period, excluding salary).

The details are given in a separate table below.

**4.2 Extra funding sources**

Expected funding from partners/customers – a total estimate.

**Project (****LRIP subproject) Leader** \_\_\_\_\_\_\_\_\_\_/\_\_\_\_\_\_\_\_\_\_\_/

Date of submission of the project (LRIP subproject) to the Chief Scientific Secretary: \_\_\_\_\_\_\_\_\_

Date of decision of the laboratory's STC: \_\_\_\_\_\_\_\_\_ document number: \_\_\_\_\_\_\_\_\_

Year of the project (LRIP subproject) start: \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

(for extended projects) – Project start year: \_\_\_\_\_\_\_

**Proposed schedule and resource request for the Project / LRIP subproject**

|  |  |  |
| --- | --- | --- |
| **Expenditures, resources,** **funding sources** | **Cost (thousands** **of US dollars)/****Resource requirements** | **Cost/Resources,** **distribution by years** |
| 1st year | 2nd year  | 3rd year | 4th year  | 5th year  |
|  | International cooperation |  |  |  |  |  |  |
| Materials  |  |  |  |  |  |  |
| Equipment, Third-party company services |  |  |  |  |  |  |
| Commissioning |  |  |  |  |  |  |
| R&D contracts with other research organizations  |  |  |  |  |  |  |
| Software purchasing |  |  |  |  |  |  |
| Design/construction |  |  |  |  |  |  |
| Service costs (*planned in case of direct project affiliation)* |  |  |  |  |  |  |
| **Resources required** | **Standard hours** | Resources |  |  |  |  |  |  |
| * the amount of FTE,
 |  |  |  |  |  |  |
| * accelerator/installation,
 |  |  |  |  |  |  |
| * reactor,…
 |  |  |  |  |  |  |
| **Sources of funding** | **JINR Budget**  | JINR budget *(budget items)* |  |  |  |  |  |  |
| **Extra fudning (supplementary estimates)** | Contributions by partners Funds under contracts with customersOther sources of funding |  |  |  |  |  |  |

Project (LRIP subproject) Leader\_\_\_\_\_\_\_\_\_/\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_/

Laboratory Economist \_\_\_\_\_\_\_\_\_/\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_/

**APPROVAL SHEET FOR PROJECT / LRIP SUBPROJECT**

TITLE OF THE PROJECT

QCD and hadron structure

SHORT DESIGNATION OF THE PROJECT / SUBPROJECT OF THE LRIP

PROJECT/LRIP SUBPROJECT CODE

THEME / LRIP CODE

NAME OF THE PROJECT LEADER : I.V. Anikin, S.V. Mikhailov, O.V. Teryaev

|  |  |  |  |
| --- | --- | --- | --- |
|  |  |  |  |
| AGREED |  |  |  |
| JINR VICE-DIRECTOR  | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| CHIEF SCIENTIFIC SECRETARY | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| CHIEF ENGINEER | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| LABORATORY DIRECTOR | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| CHIEF LABORATORY ENGINEER | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| LABORATORY SCIENTIFIC SECRETARY | \_\_\_\_\_\_\_\_\_\_\_ SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_DATE |  |
| THEME / LRIP LEADER | \_\_\_\_\_\_\_\_\_\_\_ SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_DATE |  |
| PROJECT / LRIP SUBPROJECT LEADER | \_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |  |
| APPROVED BY THE PAC  | \_\_\_\_\_\_\_\_\_\_\_SIGNATURE | \_\_\_\_\_\_\_\_\_NAME | \_\_\_\_\_\_\_\_\_DATE |